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Network Simulation of the Electronic Battlefield

Richard A. Meyer and Steve Boyle
Scalable Network Technologies, Inc., Culver City, CA
{rich, steve}@scalable-networks.com

Bob Ollerton
Space and Naval Warfare Systems Command (SPAWAR), San Diego, CA
ollerton@spawar.navy.mil

Doug McKeon
US Army Research, Development, and Engineering Command, Communications-Electronics Research, Development and Engineering Center, Space & Terrestrial Communications Directorate (RDECOM CERDEC STCD)
Douglas.McKeon@us.army.mil

Abstract

While many existing tools can simulate specific parts of wireless communication systems in detail, no single software tool, or integrated framework has been proposed to simulate the complete wireless systems including highly detailed RF propagation and radio and networking protocols. It has been shown that results from network simulation can be simply wrong and misleading when underlying devices and operating environments are not modeled appropriately. The primary reason for a lack of such integrated tools is the major computational challenge that is imposed by the combined model. This project proposes to build such an environment using HPC resources to overcome the computational challenge.

1. Introduction

Under the Electronic Battlefield Environment (EBE) portfolio, tools that provide for detailed modeling of RF propagation (EBE-2) and the electronic fields generated by complex antenna systems (EBE-1 and EBE-3) have been ported to the HPC environment. Used in isolation, these tools provide a very accurate analysis of the electronic behavior of wireless transmission and antenna performance, respectively. However, even in combination, they fail to provide a complete picture of electronic communications using those antennas.

Similarly, there are very accurate network simulation models available. QualNet[1], for example, was used in the Forces Modeling and Simulation portfolio (FMS-6) to provide fast, accurate simulation of military network scenarios[2]. However, the networking behavior is significantly impacted by the success or failure of electronic transmissions, making accurate modeling of the electronic media of paramount importance. Figure 1 is excerpted from a study[3] of the effects of physical layering modeling on network model performance. The figure shows how the use of different physical layer models, in this case bit error rate (BER) based reception versus signal-to-noise ratio (SNRT) based reception, can completely reverse the relative performance of two routing protocols.

The wireless propagation models used in QualNet are considered to be low to medium fidelity models when compared with the models used in the EBE portfolio, yet are generally acknowledged to be the best available in a commercial or academic network simulator. Limited validation against results collected in field tests has been performed using QualNet, and the overall performance of the real and simulated networks correlates well in general, but not for every specific signal.
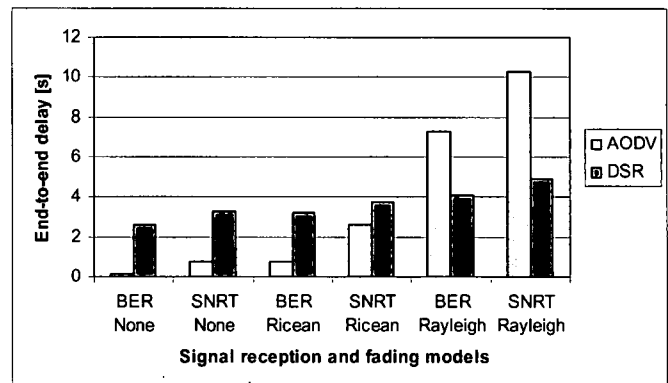

Figure 1. Effects of physical layer modeling

The objective of the project is to integrate the state of the art RF and antenna models into QualNet. The resulting Integrated Parallel Framework for Network Centric Warfare Simulations (PAWARS) will provide the first opportunity to analyze military communications systems with complete details from top to bottom, while still providing acceptable performance because of the utilization of HPC computational resources. Beyond the direct use of modeling scenarios in the greatest possible detail, the integrated environment will provide several side benefits. For example, in some situations using less than the most detailed models available will still generate a sufficiently accurate picture of the network performance. The availability of an environment with high, medium, and low fidelity models will make it possible to determine which situations are suitable for each.

Several programs in the Army and the Navy have been targeted as potential users of this technology, including but not limited to Force Network (FORCENET), Future Combat Systems (FCS), and the Joint Virtual Battlespace (JVB).

The remainder of this paper will describe the methodology followed in the integration work and will present some preliminary results.

2. Integration

Three projects in the EBE portfolio have been completed, combining to port two detailed antenna models and three propagation models to the HPC environment. The two antenna models were Printed Circuit Antenna System Simulator & Optimizer (PiCASSO), typically used for reconfigurable antenna arrays, and Electromagnetic Interactions GEneRalized (EIGER)[4], which is used to determine the pattern generated by an antenna taking into consideration the platform to which it is attached, such as a tank or ship. The three propagation models consist of VPL (Vertical Plane Launch)[5] and Quick Propagation (QPROP)[6], which are ray tracing models suitable for an urban environment, and Variable Terrain Radiowave Parabolic Equation (VTRPE)[7], an open terrain model.

A common output format was derived at the portfolio level to simplify integration of these tools for follow on projects. As previously mentioned, the QualNet network simulator was ported to the HPC environment as part of the FMS-6 project, so all of the tools to be integrated are already running in this environment, although some additional porting work is required to ensure the programs all run on the *same* HPC machines. The purpose of this project is to create an integrated parallel program and demonstrate its utility using relevant scenarios.

2.1. Scenarios.

The choice of scenarios has been critical in driving the integration work. Two military exercises are being used to generate relevant scenarios to test the PAWARS package. The first was the Future Combat Systems Communications (FCS-C) scenario used in the Boise, Idaho test in August 2003. It consisted of 20 nodes, with ground based and airborne vehicles, and there was a complete set of collected field data. The second exercise came from the Unit of Action Concept Evaluation Program (UACEP) 2002 data logs. Vignettes can be excerpted consisting of 300 to 1600 nodes.

Both of these scenarios are outdoor rural scenarios using soldiers on foot as well as ground and air vehicles. For this reason, the PAWARS project has targeted the EIGER antenna model and VTRPE propagation model for integration. Collaboration with the System of Systems (SOS-2) project team has yielded EIGER models for Apache helicopters, HMMWV transport vehicles, and Predator Unmanned Air Vehicle (UAV), as well as source code for converting the EIGER data into a form usable by QualNet.

2.2. Methodology.

Integration of antenna and propagation models is accomplished in two very different ways. Antenna data is pre-processed and read in as static data, while the propagation data must be regenerated dynamically as nodes move or change orientation.

The EIGER program is run offline to produce antenna data that can be used by either the propagation model or QualNet directly. QualNet has its own antenna model and has been enhanced to support the three dimensional data produced by EIGER. This integration is complete and preliminary data has been generated. Analysis of that data is in progress.

Integration of propagation models is more problematic. Propagation data is needed for each transmission, and must be generated anew each time a node moves. Pre-processing is impractical because of the cost of generating data for all possible pair-wise positions, orientations, and antenna types. Although ideal for performance, direct integration of the propagation code into QualNet is impractical, because source code is not available for the models. A compromised approach is being developed. The propagation program will be run dynamically as a separate process during the simulation. Mobility events will be synchronized such that all propagation information can be calculated simultaneously.

3. Results

The software acceptance test (SAT) was performed on the SGI Origin 3800 at the Army Research Laboratory and a linux multiprocessor at the author's office. The test demonstrated the portability of the QualNet software. Integration of the EBE antenna and propagation models has not been completed.

The test consisted of six test cases, using 100 to 1000 nodes/radios, varying levels of mobility, and 15% of the nodes generating 1KB/s voice-like traffic. Notably, the test cases made use of QualNet's available medium fidelity directional antenna and propagation models. The propagation model used is the Irregular Terrain Model (ITM)[8]. Once integration is complete, the performance of the QualNet models, both in terms of runtime execution and the impact on simulated network performance, can be compared with the detailed EBE models.

Selected results from the software acceptance test are presented here. Figure 2 shows the runtime as mobility increases. The dramatic increase in runtime in the cases with faster mobility is due almost exclusively to the computation of propagation effects. Because QualNet is a discrete event simulator, nodes move in discrete increments. Each move invalidates any previously calculated propagation data. This graph hints at why integration of highly detailed propagation models in a network simulator has not been attempted before. The scenario consisted of 100 nodes moving an average of 7.5 meters/second for 60 seconds, with positions being updated at 1 meter intervals. In total, there were approximately 45,000 position updates, for a total runtime of 450 seconds. Assuming that ITM would be run for each such update (which is not usually required), the computation granularity for ITM is less than .01 seconds per instance. By comparison, a single calculation using highly detailed models can take minutes, or even hours, when run sequentially.
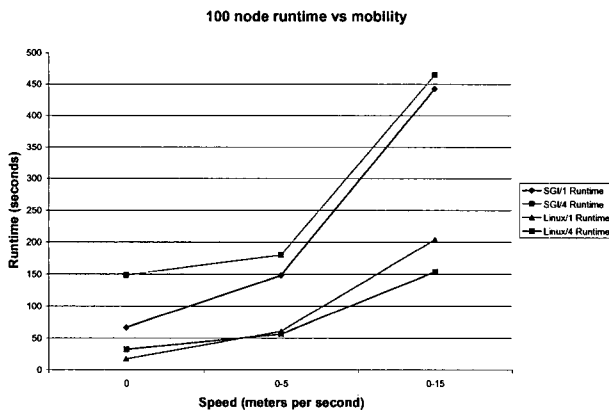
Figures 3 and 4 show two metrics of interest collected by QualNet, network latency and average throughput as mobility in the network increases. As should be expected, as nodes become more mobile, network connections are harder to establish and the end-to-end delay (latency) in delivering packet data increases.
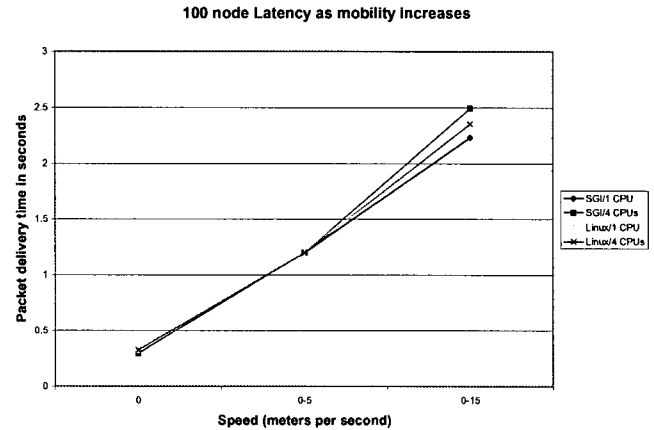
100 node Latency as mobility Increases

Figure 3. Latency versus mobility

Given that understanding, the throughput data shown in Figure 4 is counterintuitive. However, the data includes only application sessions that were successfully established. In the highly mobile scenario, only application sessions between very nearby nodes were established, and once established gave very good average throughput. These results as well can be compared with those generated following the integration of the detailed antenna and propagation models to study the impact on network performance.
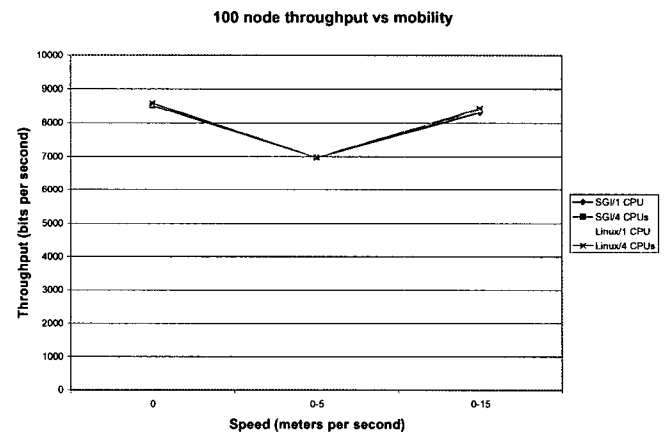
100 node throughput vs mobility

Figure 4. Throughput versus mobility

100 node runtime vs mobility

Figure 2. Runtime versus mobility

4. Work in Progress

To date, the EIGER antenna data has been successfully integrated into QualNet. Preliminary analysis of the network data and comparisons with QualNet's native antenna models are underway. Figure 5 shows the results of a simple two node scenario in which one of the nodes crosses the path of the other at a 45 degree angle. One experiment uses QualNet's native implementation of an omnidirectional antenna, the other uses the EIGER generated 3D antenna pattern for a HMMWV. The graph shows the number of signals transmitted, locked onto, successfully received, and received with errors, respectively.
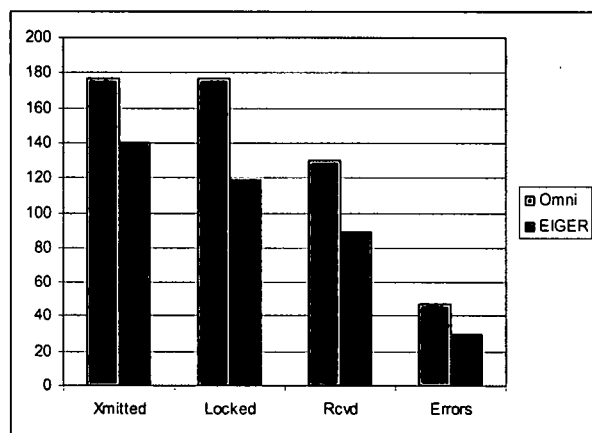

Figure 5. Antenna effects

The pattern generated by EIGER has null areas as well as strong gains. In this case, use of the detailed antenna model results in fewer signals being received clearly, and lower traffic throughput at the network level. Because of the fewer transmissions in the EIGER scenario, the simulation using EIGER takes significantly less time to run.

5. Conclusion

Because of the computational complexity, very high fidelity models of antennas and radio propagation have not been used within a network simulation environment, despite the fact that the accuracy of such models can have a significant effect on the analysis of routing protocols and other higher layer network models. This project attempts such an integration, using models that have already been ported to a high performance computing environment. Preliminary results based on the integration of the EIGER antenna model have shown a significant impact on the prediction of higher layer protocols. Integration of similarly detailed propagation models is expected to show a similar impact.

The availability of massively parallel machines should dramatically improve the performance of such an integrated system, making it an attractive tool for use in military programs requiring an accurate picture of their network performance.

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